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CONTRIBUTIONS AND BIBLIOGRAPHY.

SOME OBSERVATIONS ON TEMPERATURES AND WINDS AT MODERATE ELEVATIONS ABOVE THE GROUND.

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[Dated: Aerological station, Drexel, Nebr., May 16, 1919.]

SYNOPSIS.—This article is based on the free-air observations by means of Marvin-Hargraves kites begun at Drexel, Nebr., in October, 1915.

Average annual temperature gradients in the lower air over any region are dependent largely on the intensity and persistence of the winter temperature inversions. for in summer surface heating produces local convection which results in nearly uniform vertical temperature gradients over wide areas. The gradient at any time is dependent largely on wind direction at different levels, especially in winter.

The winter vertical temperature gradients over Drexel are the result of the successive cold and warm-wave conditions. In the cold wave the cold air arrives first near the surface and gradually affects higher levels. Near the ground turbulence and heating by day may maintain a thin sheet in which there is a lapse in temperature, but the general condition is one of inversion. Near the center of the anticyclone dynamic warming by the compression of the descending air is sometimes in evidence aloft. Then a shift of wind to south will raise the temperature at some distance above the surface several hours before the slower-moving surface wind arrives.

The degree of diurnal change of surface wind depends on the vertical temperature gradient as well as on the relative velocities of the upper and lower winds, convectional interchange being greater when the gradients are steepest.

Gradient winds computed from sea-level isobaric charts frequently do not agree at all closely with those observed a few hundred meters above the surface at Drexel (itself at 396 m.), for, aside from arbitrary assumptions in sea-level reductions, the diverse temperatures of the air over neighboring regions may make the slopes of the isobaric surfaces even at moderate heights differ considerably from those indicated by the sea-level charts.—*C. F. B.*

INTRODUCTION.

A large portion of the readers of the REVIEW other than those actively engaged in upper-air work find it hard to interest themselves in the mere tabulated record of upper-air observations. As the period of observations at any aerological station becomes longer, I believe a more descriptive treatment can be given the published results. This, in my opinion, should encourage a more general study and discussion of upper-air data among those who have heretofore looked upon these records as something rather foreign to their own work and lines of thought.

THE "LAPSE-RATE" OF TEMPERATURE.

In a table of average annual free-air temperatures over practically any station a continuous "lapse" in temperature with elevation from the ground to the isothermal layer, or stratosphere, is shown. This word "lapse" is taken from the English publications as more appropriate than the awkward alternative, "positive vertical temperature gradient." The expression "inverted rate" is used to convey the opposite meaning. The lapse rate varies somewhat for different places, according to their latitude, altitude, and exposure, but it is probable that the tendency of this rate for successive large intervals of elevation, as shown by data already available, is universal.

GENERAL CONDITIONS AFFECTING GRADIENTS.

A discussion of the processes arising out of insolation, radiation, and convection that establish and maintain these vertical temperature gradients would only be a repetition of an already exhaustive treatment of the subject. By way of introduction to the subject of this paper, which it is intended to confine to observations on temperatures and winds at moderate elevations, it need only be pointed out that the lapse rate on the average increases from the ground to nearly the isothermal layer; that from about 4,000 meters altitude to about 9,000 meters it approaches the adiabatic rate for dry air, and is rather uniform with altitude, season, and place; and that below about 4,000 meters the lapse rate averages approximately half the adiabatic rate for dry air, but with marked differences between the seasonal means.

Winter vs. summer gradients.—The limitations imposed on the lapse rate by convection and the liberation of latent heat of condensation of the moisture content of the air operate to maintain a comparatively uniform rate over different inland places in summer; while in winter a lower lapse rate (or greater inverted rate) can be inferred for higher latitudes and longer continental exposure. It will therefore be found that the variation in the average annual vertical temperature gradients below about 4,000 meters, for different inland places, is largely determined by the different winter values of these rates.

Wind and temperatures aloft.—The influence of wind direction and force on vertical temperature gradients is apparent when comparing daily free-air gradients with the normal gradients for the season. Seasonal averages are simulated frequently on summer days, but more rarely in winter, the deviations from the normal winter curve increasing in frequency and amount as lower altitudes are considered. This is a result of the steeper horizontal temperature gradients, the greater wind force, and more abrupt changes in wind direction prevalent in winter. A consideration of the free-air records of Drexel, Nebr., as bearing on the relation of winds and temperatures at altitudes well below 4,000 meters, or within the usual range of kite flights, may be of interest, from the fact that the central location of this station is representative of considerable of the interior portion of the country and affords data in this respect heretofore not available for a typical continental exposure.

Thunderstorm due east of Pensacola, Fla., 9 a. m. (90th mer. "summer time"), Aug. 26, 1918. Photographed by Lieut. W. F. Reed, jr., U. S. N. R. F. (Published by permission of the Navy Department.)

Observations at 9 a. m.: Showers due east and due west of station moving northward; lightning and thunder; barometer 30.06 in.; temperature, dry bulb 85.0, wet bulb 78.0; wind SE., 8-9 mi/hr.; clouds, .3 Ci. and .2 Ci.St. from NW., .1 Cu., .3 Cu.Nb. and .1 St. from S.

WINTER VERTICAL TEMPERATURE GRADIENTS OVER DREXEL.

Table 1 gives seasonal free-air temperatures and gradients for Drexel, determined from about two and a half years' record. A change that will to some extent affect the values of the gradients may be expected from additional years of observations, but the tendency or direction of the curve indicated by the gradients will undoubtedly remain the same. These figures are, moreover, frequently given partial verification by observations on days that seem typical of their respective seasons.

The winter temperature gradients at Drexel well illustrate its continental exposure. To verify further the figures in Table 1 for the colder portion of the year, an effort has been made to compute 24-hour mean gradients for altitudes extending to 2,000 meters above sea level, or about 1,600 meters above station, above which the diurnal change is usually not large. The result, shown in Table 2, was determined from the records of such continuous 24-hour free-air observations as were occasionally possible during a period of nearly four years, and therefore represents averages based on observations varying in number for the different months.

Table 2 qualifies the corresponding data in Table 1 only as typifying a more stagnant state of the atmosphere, inasmuch as Table 1 is the mean of all available observations, while the observations included in Table 2 were mostly taken in clear weather. Table 2 should furthermore be accepted with the reservation that it is based on decidedly fewer observations than Table 1. Further reference to these tables will be made in the following paragraphs.

As, on the average, the winter radiation, during a 24-hour period, is far in excess of the concurrent insolation, and as this excess is not easily offset by warm winds, owing to remoteness from large bodies of water, the tendency is for an accumulation of cold air over an extended area. This cold layer is stagnant as regards ability of the warmer winds above to intermix with it, and consequently builds up until a well-defined storm or low pressure area dispels it. Table 1 illustrates the comparative permanence of this cold layer above the ground in winter, and Table 2 its progressive deepening with advance of the season. It is conceivable that the cold waves that at intervals visit a considerable portion of the country throughout the winter, owe their inception to just such processes in the regions to the north and northwest, whereby extensive, rather deep masses of cold air build up, consequent upon a prolonged undisturbed radiation.[1]

A number of instances of this persistence of low temperatures in the layers near the ground may be found in the published records of free-air observations taken continuously for 24 hours or more. A good type of winter vertical temperature gradients during a period when normal surface temperatures prevailed, is afforded by the diurnal series record of February 14–15, 1916, (**2**). It will be noted that an inversion at an average altitude of about 1,400 meters above sea level, or 1,000 meters above the ground, was continuous throughout the 33 hours of the series, and that insolation during the day was effective in restoring the normal lapse rate in a layer extending only a few hundred meters above the ground. Above the inversion layer, and extending to about 3,100 meters from the ground, a lapse rate was maintained, and the temperature showed only slight diurnal variation till about the last 12 hours of the series, when a sustained rise in temperature, preceding and attending a steady fall in pressure, set in. The rise in temperature in the higher layers was not uniform with altitude, as is apparent in the small scattered inversions at various heights.

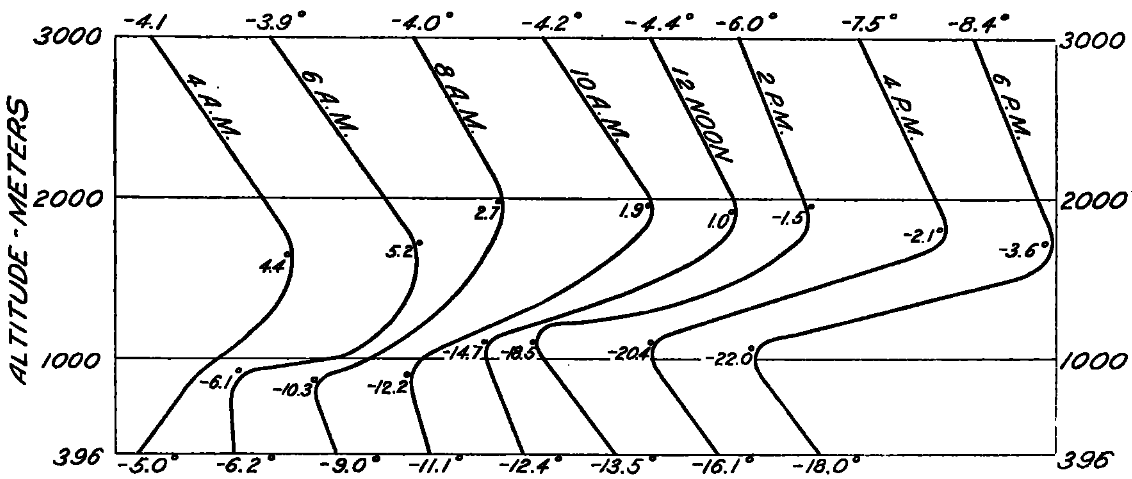

FIG. 1.—Progressive temperature gradients in cold wave of Dec. 27, 1917, at Drexel. Temperatures in °C.

The afternoon rise in temperature in the layers immediately above the ground, plays a part in establishing the small average winter lapse rate in the very lowest layers, as shown in Table 1, and suggested in the midwinter month in Table 2. While the observations entering into Table 1 were made principally in the daytime, this reversal of the inverted rate near the ground in winter is not necessarily confined to the daylight hours. Due to the prevalence at this time of year of winds that are cold at their base, but which, on account of the retardation and vertical currents induced by surface friction, show lowest temperatures at that small altitude above the ground where surface friction is for the most part surmounted, a lapse rate may be evident the first two or three hundred meters above the ground, irrespective of the time of day. Low-lying clouds, prevalent in winter, also play an important part in establishing a lapse rate from the ground to their base.

Progressive vertical temperature gradients in a cold wave.—Figure 1, adapted from the chart accompanying

[1] Cf. MONTHLY WEATHER REVIEW SUPPLEMENT No. 12 (Aerology No. 7, pp. 9-12; and MONTHLY WEATHER REVIEW, 46, No. 12, pp. 570-580.—W. R. G.

the record of the diurnal series of observations taken on December 26–27, 1917 (3), shows successive vertical temperature gradients at two-hour intervals during the advance of a cold wave. This graphic method, differing from the chart from which it is adapted, in that the temperature lines are isochronous instead of isothermal, has been chosen as possibly representing a vertical plane in the line of advance of a cold wave. (The same method has been used in graphically illustrating a warm wave in fig. 5.)

Figure 1 fully confirms the conclusion advanced by Clayton (4), that a cold wave advances in inclined strata, and that the temperature falls first near the ground, and progressively later at higher altitudes. It is apparent, however, that the rapid fall in temperature is limited to some comparatively low altitude, probably not exceeding 1,000 meters above the ground. The obvious inference that the depth of the strata of rapidly falling temperature shows some coordination with the intensity of the cold wave and the magnitude of its causative HIGH seems well borne out by observation.

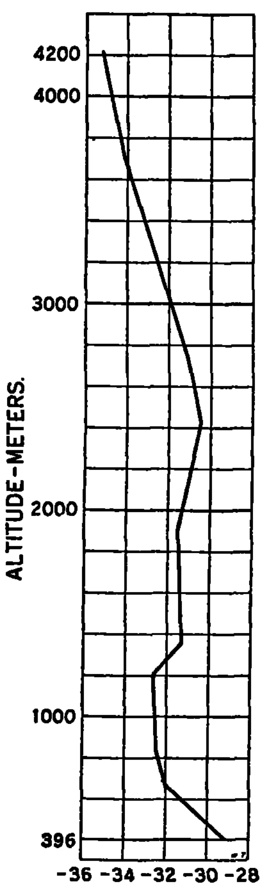

FIG. 2.—Temperature gradient, 11.30 a. m., Jan. 11, 1918, at Drexel.

Vertical temperature gradients at the culmination of a cold wave.—A lag in the rate of temperature fall in the apex of the cold wave probably takes place at some intermediate stage in its progress, while the temperature fall in the higher layers—slow at first—continues steadily till the culmination of the cold wave. The slower fall in the higher altitudes is in accord with the opinion hereinbefore given of the possible origin of cold waves in the lower strata, and the assumed smaller horizontal temperature difference with increasing altitude.

A plausible explanation of the apex of the cold wave becoming first evident near the ground, and later at higher altitudes, is that the cold air can not advance until a temperature gradient to the ground, equal to or less than the adiabatic rate, is established. It is manifestly impossible for a stratum of air that is subject to agitation in a vertical direction to make much horizontal progress, so long as it is potentially colder than the air beneath it. The apex of the cold wave will eventually rise to that altitude in the forward moving stratum of cold air where the wind velocity is the greatest.

If a cold wave, such as depicted in figure 1, culminates at night, the layers of air near the ground, and, to some extent, those of higher altitudes, will cool further by radiation, until a more or less isothermal condition of cold air extending to a considerable altitude, results. Figure 2, taken from the record of free-air observation on January 11, 1918 (5), shows the vertical temperature arrangement on the coldest day of the winter of 1917–18. The observation was taken soon after the crest of a period of rising pressure had passed.

It will be noted that the lowest temperature, −35.1° C., at about 4,200 meters altitude, was but a few degrees lower than the morning surface temperature, although considerably lower than the mean winter temperature for that altitude given in Table 1. Owing to the fact that the winter of 1917–18 was unusually cold, figure 3, taken from the second of the series of diurnal observations on January 27, 1916 (6), is shown as representing a more nearly typical condition. In this graph, the shallow depth of the stratum of low temperature is at once apparent; while at higher altitudes, temperatures appear to be about normal for the season. In the higher altitudes, however, the winds had backed to strong west and southwest, showing that a recovery of temperature had

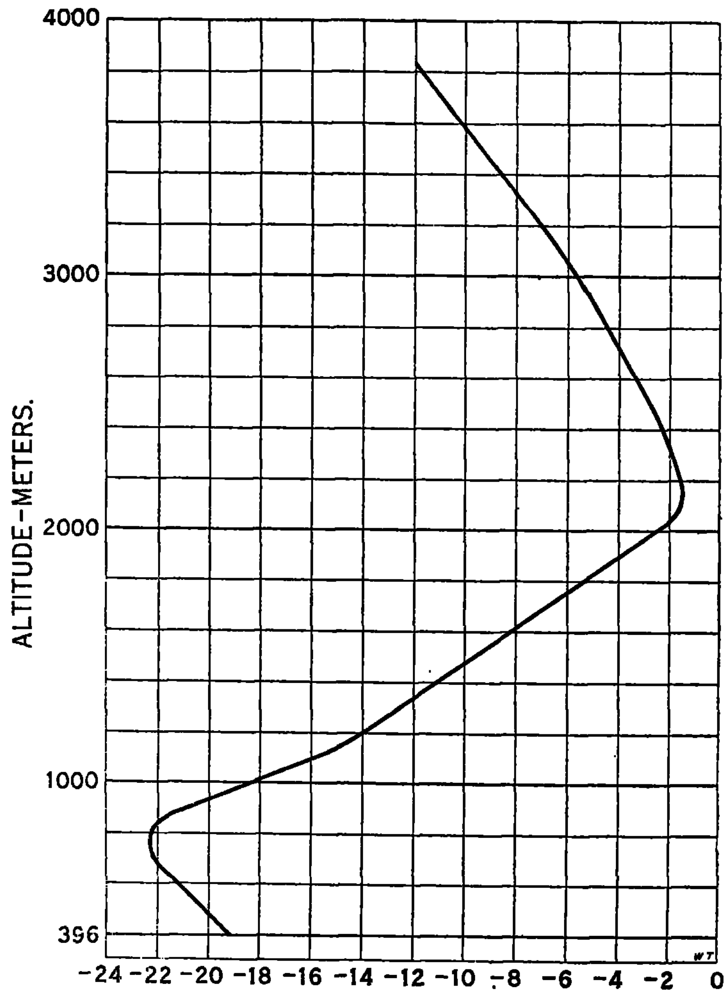

FIG. 3.—Temperature gradient, 11 a. m., January 27, 1916, at Drexel.

probably already begun, although the surface pressure was still rising. During the observation of January 11, 1918, the winds were from a general northwesterly direction and of gale force from the ground to the highest altitude reached.

It appears that the outstanding feature of cold waves is at first a rapid fall in temperature at moderate altitudes above the ground; and that the fall in temperature in the higher altitudes, and the subsequent fall at all levels depends on the magnitude—but principally on the persistence—of the accompanying HIGH or succession of HIGHS. A persistence of high pressure, or a rapid succession of areas of high pressure, is apparently correlated with a deepening, through radiation, of the already cold masses of imported air.

Presumably, radiation continues to cool the elevated strata during the prevalence of high pressure until low temperatures are reached, after which further cooling of the surface layers to temperatures much below that of the

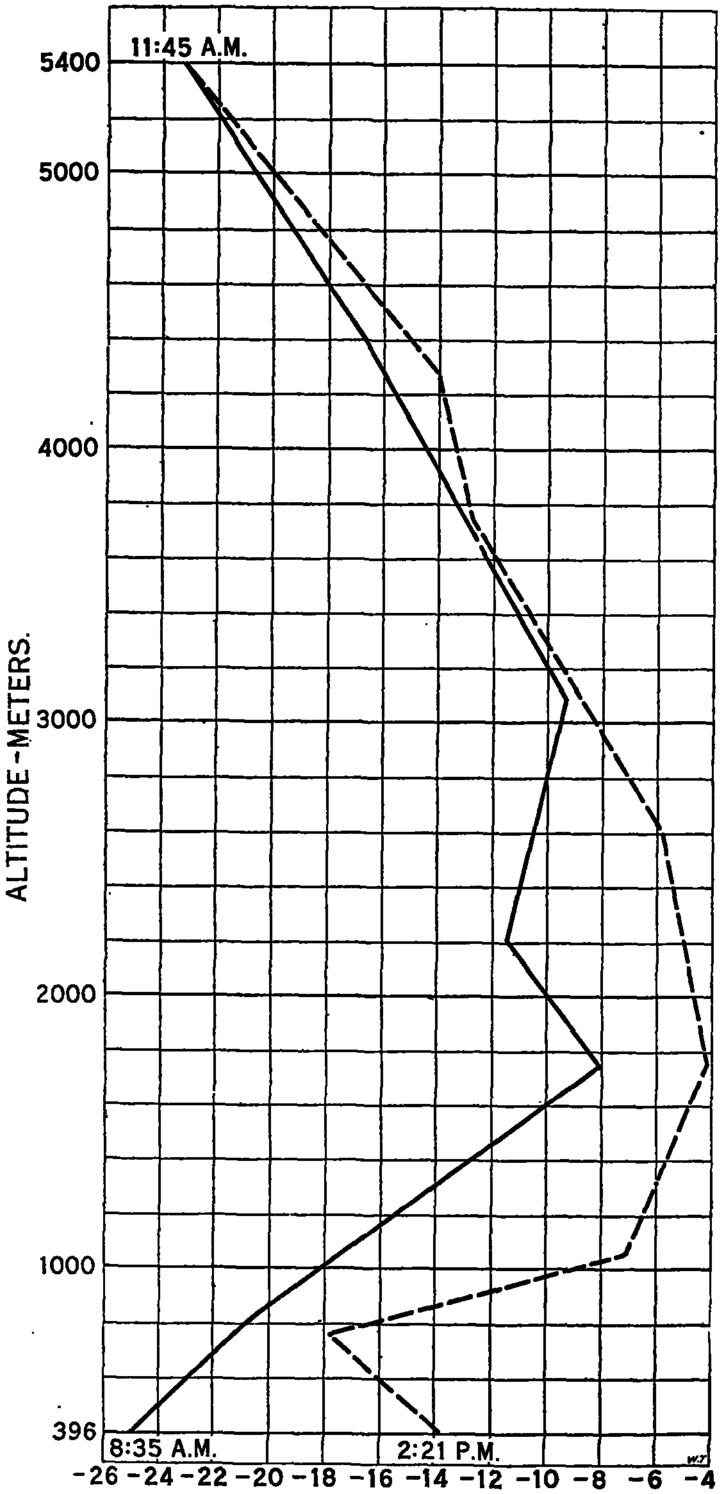

FIG. 4.—Temperature gradients at Drexel, Feb. 1, 1918.

layers aloft is held in check by the fact that the rate of radiation becomes less as the temperature becomes lower. Insolation is therefore effective in limiting the possible minimum temperature on the ground and the layers of air immediately above, when conditions are favorable for prolonged radiation. A vertical temperature gradient such as that shown in figure 2 may be inferred as the final result of persistent high pressure in winter.

Recovery of temperature after a cold wave.—Apparent evidence of dynamic heating of descending air in the crest of a HIGH is occasionally shown when an observation under those conditions is possible at night. The last observations in the diurnal series of January 2–3, 1919 (7), made in the crest of a cold high-pressure area showed a rise in temperature in the higher altitudes before insolation had begun or a change in wind direction had taken place.

Figure 4 illustrates an early stage in the temporary recovery of temperature, due to changing winds, during an extended period of cold weather. The graphs show the temperatures during the ascent and descent of a kite in the first flight of the diurnal series of February 1–2, 1918 (8), when the crest of a high-pressure area had just begun to recede and a low-pressure area was advancing from the north. A rise in temperature in the interval between ascent and descent is noted below 3,000 meters, being well pronounced in the layers from about 2,500 meters to the ground. An examination of this and subsequent observations extending over an approximately 28-hour period shows that, as an accompaniment of falling pressure, the wind near the ground was generally southwest, while at higher altitudes up to 3,500 meters, the winds that had previously been west-northwest gradually became southwest; also that the rise in temperature below 3,000 meters eventually became concentrated in a sustained relatively warm stratum extending from about 300 to 1,000 meters above the ground. From 3,000 meters to 3,500 meters and presumably at higher altitudes, to which heights observations after the first flight did not extend, the rise in temperature was small.

These conditions, connected with the recurrence on February 3, 1918, of cold northwesterly winds of gale force attending a rapid rise in pressure, illustrate the temporary moderating influence of a LOW bridging two vigorous HIGHS and lead to the inference that the influence of this particular LOW probably did not extend much higher than 3,000 meters above the ground.

Progressive vertical temperature gradients in a warm wave.—In support of the partial evidence deduced from the foregoing that a tendency for an increasingly warm stratum of air to become pronounced at successively lower altitudes is perhaps as typical of the front of a LOW as the characteristic rise in temperature itself, figure 5, taken from the diurnal series of observations of October 16–17, 1917 (9), is produced. This graphically shows the progress of a warm wave that became evident in the early evening hours, or about 12 hours after a fall in pressure set in. An over-running warm current, of which this is a good example, is discernible as a rule only in night or early morning observations, particularly in clear weather, as the warming effect of convectional currents tend to mask other causes of rising temperature by day.

It will be noted that this warm wave first became evident principally at about 1,000 meters above the ground, from which altitude the apex of the advancing current of rising temperature gradually descended to about 400 meters. The combined effect of rising temperature aloft and cooling by radiation in the layers near the ground in causing a steep inverted gradient is significant of the small tendency of warm air aloft to intermix with the cooler air below. In such a circumstance clear weather in the morning will cause a rapid rise in temperature on the ground until the inversion temperature is exceeded, inasmuch as insolation will then be available to heat, through the medium of convectional currents, only the comparatively thin stratum of air comprising the inverted gradient.

Possible characteristic air movement in the front of a LOW.—The altitudinal progress of the warm wave, opposite in direction to that of the cold wave, admits of an easy explanation. It may be assumed that the warm wave represented a south-to-north drainage from a mass of air probably not much more than 1,000 meters deep, that had previously been abnormally warmed by insolation. The well-understood rising of isobaric surfaces in strata above the ground, contingent upon unequal heating or cooling in a horizontal direction, would then cause a flow of warm air from south to north. This flow would be evident first at the altitude of the top of the column, because there the isobaric gradients would be steepest and the wind consequently strongest. The air brought in by the successively lower and slower winds would also be increasingly warmer, as would be expected from a column of air warmed by insolation and convection.

It is apparent that an overflow of air from a warm column does not necessarily imply a return current near the ground, but that under certain conditions the consequence of temperature difference between adjacent columns may be a general movement of air from warmer to colder. The displaced air is undoubtedly compensated by a return current in another more or less remote vertical plane. The warm wave cited occurred in the front of a LOW that advanced from the southwest, but whether it was simply incidental to the circulation in the front of the LOW, or, in view of the possible circumstance offered in its explanation, was a contributing factor to the development of the LOW, is a matter for conjecture. The question of cause and effect in this instance suggests some of the reasons offered by Prof. Bigelow in support of his countercurrent theory of storms (10).

Cyclonic and seasonal temperature cycles.—If figures 1, 2, and 5, in the order given, be imagined as representing a complete cycle of temperature fall, minimum, and recovery, a seasonal parallel cycle is apparent in Table 2. If the figures in Table 2 be accepted as approximately average gradients, and noting that January is the coldest month, the conclusion is suggested that the inverted gradients in late autumn and early winter are in large part the resultant of under-running cold winds, and in late winter and early spring the resultant of over-running warmer winds. The small inversion rate extending to a considerable altitude in January could be explained in much the same way as the approximately similar vertical gradients in figure 2.

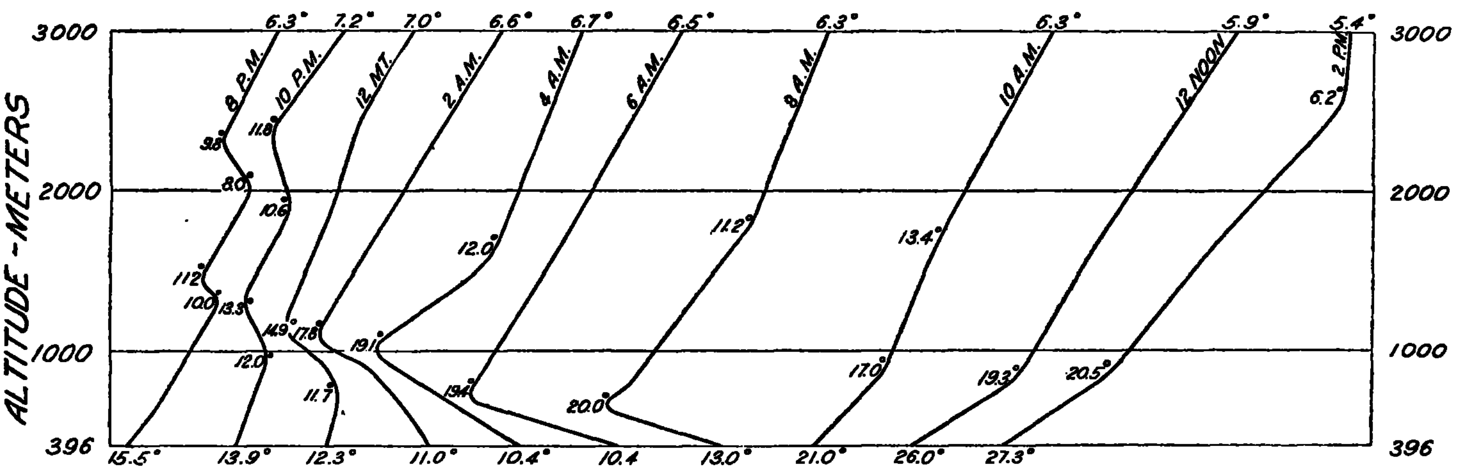

FIG. 5.—Progressive temperature gradients in warm wave of Oct. 16-17, 1917, at Drexel. Temperature in °C.

DIURNAL CHANGE IN WIND VELOCITY AND DIRECTION.

An examination of the data contained in the observations from which figure 5 was drawn suggests some comments on the generally accepted explanation of change in surface wind direction and velocity with diurnal change in temperature. That the descending air, reciprocal to the rising currents due to insolation, by retaining much of its original momentum after reaching the ground, is wholly effective in causing the observed veering in direction and rise in velocity of surface winds, is probably open to question.

The well-marked evidence of this phase of diurnal wind change shown in the record of October 17, 1917, would amply justify this explanation, were it not that there is frequent apparent contradiction to it. While convection currents have a marked influence in checking the velocity of winds aloft, it is quite possible that a compensating rise in surface velocities is only partially realized, the energy of the lost motion of the upper currents being probably conserved through thermal changes.

On the date referred to the morning rise in velocity and veering in direction suggests an explanation connected with the pressure distribution which, it will be noted, showed the common circumstance of an observation taken in the periphery of a LOW. Accepting the supposition that convection currents are a complement to converging circulation in a LOW, in that they aid by removing that surplus upward, it is apparent that on a clear night, convection in the low strata near the ground that have become cooled by radiation being inhibited, converging winds are consequently retarded, if we disregard the influence of friction. With the dispelling of the inverted temperature gradient by insolation, a release of the air via convectional currents is effected in the low strata within the LOW, thereby accelerating the converging circulation. The increased velocity of the converging winds near the ground enables them to veer toward a direction more nearly parallel to the isobars.

Local convection and gustiness.—It is probable that the normal daytime rise in surface wind velocity is also to a large extent due to the independent disturbing effects of convectional currents, aided by a slight pressure gradient. When conditions favor strong convectional currents, and pressure gradients are weak, kite flights abundantly show that the horizontal currents come in surges at more or less regular intervals, the effect of which on velocity records is largely lost in the ordinary method of registering wind from a Robinson anemometer.

The surges in wind velocity attending convectional currents often show a wide oscillation in direction when the amplitude of the surges is well marked. The oscillations may have a range of 90 or more degrees in azimuth (as, for example, from west to southwest and back again) at intervals a few minutes apart, and tend to be synchronous with the surges in velocity. It is probable that after horizontal currents are once established by convection and pressure gradient their future path is oscillatory, for reasons similar to those given by Sandström in discussing the relation of pressure gradient and wind (**11**). The fact that winds aloft, at even moderate elevations above the ground, change in direction but slowly attests to the comparative freedom of these oscillating convectional winds from influence of the steadier winds aloft.

Convectional currents sometimes appear to give a progressive wind a wave-like course, in which an interchange of velocities as well as temperatures between the surface air and that aloft no doubt takes place. To what extent a sinuous path in a vertical direction is real and to what extent apparent, is well brought out in some recent observations on smoke as an indicator of gustiness and convection (**12**). In a line of kites flying at a low angle the illusion of waves in the air is sometimes complete, the kites being successively elevated and depressed as the gust passes along the line. While a strong ascending current is easily discernible in the behavior of a kite rising in it, evidence of an actual descending current immediately preceding or following it is not conclusive, owing to the weight of the kite.[1]

Over-riding winds not always affected by convection.—In the case of steady winds, it would appear that convection and viscosity play only a small part in fixing the velocities at the various altitudes, except as convection is effective in retarding them. In the morning, an inversion layer near the ground acts as a barrier in limiting convectional currents to the strata intervening between it and the ground, until an adiabatic rate to the ground has been established. That the intensifying of convectional currents is not necessarily productive of higher surface velocity, even when strong winds prevail at a small altitude above the ground, is occasionally shown by kite flights.[2] On the morning of January 9, 1919 (**13**), a free-air observation showed that while the wind velocity a few hundred meters above the ground rose from strong to gale force, the surface velocity fell from light to almost a calm, notwithstanding the fact that the surface temperature rose during the same time. The pressure gradients shown by the morning map of that day were weak over Drexel; also the surface wind did not increase until a steady fall in pressure set in a few hours after the observation. The rise in surface velocity was coincident with a change in direction from northerly to southerly (from the south). It seems conclusive that in this case whatever effect on surface velocity might be attributed to the winds aloft, was an indirect one—that the rather abrupt rise in velocity with altitude observed in the morning contributed to, and was a forerunner of, the fall in pressure that followed.

[1] Evidence of such descending currents is, however, often conspicuously apparent during ascensions with captive balloons. At Mount Weather, Va., such balloons were used on days when kites could not be flown because of light winds, and it was often necessary, especially during summer days, when convection was particularly active, to watch the reel closely, in order that the wire should be let out only at such speed as would enable the balloon at all times to keep the wire taut. Alternately ascending and descending currents produced large variations in this speed, especially at levels between the surface and one or two hundred meters above it; in several instances descending currents were so pronounced as to cause the balloon to drop slightly and the wire to kink, and in two cases a succeeding ascending current, combined with the lift of the balloon, caused the kinked wire to break and the balloon to escape.—W. R. G.

[2] In such cases the temperature of the strong wind is potentially warmer than that at the surface, and, therefore, the convectional columns tend to flatten out against the base of the strong wind rather than to enter it.—C. F. B.

SEA-LEVEL PRESSURE GRADIENT, VERTICAL TEMPERATURE GRADIENT, AND CHANGES IN WIND VELOCITY WITH VARYING ELEVATION ABOVE THE GROUND.

Instances of wind velocities at some moderate altitude decidedly exceeding those called for by mathematical formula applied to sea-level pressure gradients, are quite frequent. Over Drexel such a condition is often connected with a pressure distribution defined by low pressure to the north, and isobars of small curvature extending approximately west-east. Surface winds will then blow from a general southerly direction, while at no great altitude aloft they will be from the west.

The free-air observation of January 26, 1919 (**14**) begun almost simultaneously with the surface observations shown on the morning map of that day, was made in the counterpart of such a pressure distribution. A south-southwest surface wind of between 4 and 5 m. p. s. soon changed to 17 m. p. s. from the southwest at 300 meters altitude, and became successively west-southwest at 600 meters, and west from about 1,000 meters to 3,100 meters. The velocity diminished slightly from 300 meters to about 1,000 meters, above which it increased again to 20 m. p. s. at 3,100 meters.

The surface pressure distribution that morning over Drexel showed a gradient toward the north of about 1 millibar in 120 kilometers. Neglecting the slight curvature of the isobars, which may have been straight, this gradient by formula indicates a velocity of about 6.5 m. p. s., or about one-third the velocity actually observed 300 meters above the ground.

The suggested explanation for the abrupt increase in velocity under the conditions cited, is associated with the general west to east declivity of the western Mississippi Valley and Plains States, and the resultant adiabatic heating, through compression, of currents directed toward the east. If, as a result of this adiabatic heating, the layers of air become warmed, relative to those at the same altitude farther north, the consequent lifting of the isobars over the relatively warmer region will cause steeper gradients toward the north, and increased velocities toward the east. When this condition obtains on a clear night, surface friction and the cooling of the low layers by radiation, will be effective in retarding the velocities near the ground.

The possibility of such a process operating to raise temperatures aloft is suggested in the night observations taken during the diurnal series of December 21–22, 1915 (**15**), although evidence of the rise in temperature being effective in increasing velocities is not conclusive in these observations. A continuous wind from a general westerly direction is noted during the night hours at altitudes ranging from about 300 meters above ground to approximately 1,600 meters. At the base of this west wind, the temperature rose from 4° C. at 6 p. m. to nearly 11° C. at 5:30 a. m.

Abrupt rises in wind force at altitudes coincident with nocturnal inversion levels are frequent, particularly in south winds, and under such circumstances, velocities at some moderate elevation above the ground decidedly higher than that indicated by surface pressure gradients are not uncommon. A pronounced example is shown in the free-air observation of July 21, 1918 (**16**), in which a rise in velocity from 2.7 m. p. s. on the ground to 25.8 m. p. s. at about 300 meters above the ground was recorded. Surface pressure gradients as shown on the morning map of that day were weak.

Diurnal amplitude in velocity of south winds.—In view of the fact that abrupt rises in velocity at the inversion layer are most frequently observed and most pronounced in south winds, reference is again made to the analysis of the warm wave of October 16-17, 1917, as offering a partial solution. It was early noted at Drexel that following a clear day during which the winds were too light to launch a kite, a kite flight was generally possible in the early evening hours, or as soon as radiation had begun, the possibility amounting to almost a certainty if there had been steady air movement from the south during the day.

An explanation can be reconciled with these observed facts by considering convectional currents as tending to dampen the flow of air by day, and warm air aloft as overrunning the cooler air near the ground at night, unimpeded by vertical currents. If the air movement is from a warmer region, the rise in velocity at and above the inversion layer appears to be due to conditions analogous to the warm wave referred to in the previous paragraph.

When the wind sets in from the south, a period of falling pressure is usually indicated. In the initial stages of falling pressure the winds are likely to be light from some southerly direction, with a tendency to veer with altitude, except that in the lower altitudes stronger winds will be found at night if conditions favor an inversion in temperature. A deepening as well as a strengthening of winds from the south seems to attend the approach of a center of low pressure. The night excess over daytime velocities at moderate elevations above the ground, although probably limited to fair weather, seems to persist until the more vigorous circulation near the center of the LOW checks the effect of convectional currents.

While in the case of a pronounced warm wave, the stratum of maximum temperature change appears to occur in the lower levels and to become progressively lower in altitude—as already pointed out—a slower rise in temperature, extending to higher altitudes, is no doubt an attendant feature. Evidence of this is more especially apparent in summer observations, when a gradient indicating general winds from the south is likely to prevail for a number of days. The conditions discussed in this and the previous paragraph are illustrated in the free-air observations of July 1–3 and September 21–24, 1918 (**17**).

Nocturnal temperature inversion and wind velocity.—Strong winds are often observed at the summit of a nocturnal inversion under circumstances that do not readily admit of the explanation just given, as for instance, when no rise in temperature at the altitude of the strong wind is observed, or when the direction of the wind is other than from the south. In such cases it may be inferred that the velocity indicated by the surface pressure gradient is not attained until an altitude is reached where the air rendered stagnant by radiation is surmounted. The velocity at this inversion level may, moreover, be augmented by a further inclination of the isobars aloft, caused by an unequal cooling in a horizontal direction of the air layers near the ground, or a cooling of columns of air made unequal in height by topography. When the pressure distribution is such that the normal increase in velocity with altitude fails, the effect of nocturnal radiation on velocity is sometimes apparent as a comparatively thin stratum of strong wind near the inversion level, with light winds extending below to the ground, and above to a considerable altitude. The free-air observations on August 26 and 27, 1918, are cited as illustrations.

CONCLUSION.

In the lower air strata it is apparent that causes for deviations from the normal or average vertical temperature gradient are in the main due to changes arising out of cloud formation and dissipation, foehn-like processes, nocturnal radiation, and various modifications in intensity and depth of the cold wave and warm wave phenomena illustrated in figures 1 and 5. Combinations of some of these causes also certainly occur.

The mean temperature gradients in the various quadrants of HIGHS and LOWS for Mount Weather (**18**) seem qualitatively to represent conditions for Drexel as well. It is, however, quite certain that corresponding average winter curves for Drexel will show more pronounced differences in opposing quadrants in both HIGHS and LOWS.

TABLE 1.—*Mean seasonal and annual temperatures and temperature gradients at Drexel, Nebr.*

Altitude, sea level.	Spring. Mean, Δt/100m.		Summer. Mean, Δt/100m.		Autumn. Mean, Δt/100m.		Winter. Mean, Δt/100m.		Year. Mean, Δt/100m.	
Meters.	° *C.*	° *C.*	° *C.*	° *C.*	° *C.*	° *C.*	° *C.*	° *C.*	° *C.*	° *C.*
396	10.3	......	23.7	......	11.7	......	−6.4	......	9.8	......
500	9.6	0.67	23.0	0.67	11.3	0.38	−6.6	0.19	9.3	0.48
750	7.9	0.68	21.4	0.64	10.2	0.44	−6.5	−0.04	8.2	0.44
1,000	6.8	0.44	20.1	0.52	9.2	0.40	−5.6	−0.36	7.6	0.24
1,250	5.8	0.40	18.5	0.64	8.4	0.32	−4.7	−0.36	7.0	0.24
1,500	4.8	0.40	17.0	0.60	7.6	0.32	−4.6	−0.04	6.2	0.32
2,000	2.5	0.46	13.7	0.66	5.4	0.36	−5.3	0.14	4.1	0.42
2,500	−0.2	0.54	10.2	0.70	2.8	0.52	−7.1	0.36	1.4	0.54
3,000	−3.0	0.56	6.8	0.68	0.0	0.56	−9.5	0.48	−1.5	0.58
3,500	−5.9	0.58	3.4	0.68	−2.8	0.56	−11.9	0.48	−4.4	0.58
4,000	−8.8	0.58	0.2	0.64	−5.5	0.54	−14.6	0.54	−7.3	0.58
4,500	−12.1	0.66	−3.1	0.66	−8.0	0.50	−17.6	0.60	−10.3	0.60
5,000	−15.4	0.66	−6.3	0.64	−10.6	0.52	−20.8	0.64	−13.3	0.60

TABLE 2.—*24-hour mean temperature gradients, November to March, at Drexel, Nebr.*

Altitude, sea level.	November.	December.	January.	February.	March.
	Δt/100m.	Δt/100m.	Δt/100m.	Δt/100m.	Δt/100m.
Meters.	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*
396	......	......	......	......	......
500	−1.00	−0.78	−0.19	−1.64	−0.74
750	−0.18	−0.15	0.08	−0.78	−0.16
1,000	0.24	0.05	−0.17	−0.51	0.32
1,250	0.34	−0.38	−0.09	−0.40	0.35
1,500	0.39	−0.02	−0.05	0.01	0.33
2,000	0.56	0.48	0.11	0.40	0.51

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